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Arina Negoiţescu, Adriana Tokar, Daniel Ostoia

A Study Regarding the Performances of Trigeneration Systems

In this paper a tri-generation system will be evaluated which is based on a cogeneration subsystem for the production of heat and power (CHP), and a Salt-Water Energy Accumulation & Transformation subsystem (SWEAT) for the production of cold. The system will be designed to produce 220V AC electricity, heat for space heating and hot tap water (about 70^{O}C) and cold at about 10^{O}C for air conditioning. The paper presents the modelling and simulation study of the CHP subsystem to obtain an indication of the amount and quality of heat generated by the CHP subsystem.

Keywords: *trigeneration, efficiency, cooling, heat, power*

1. Introduction

Trigeneration implies the simultaneous production of mechanical power (electricity), heat and cooling from a single fuel.
Conventional thermoelectric stations convert only 1/3 of the fuel energy in electricity. The rest is losses in the form of heat. The adverse effect to the environment from this waste is obvious. The need to increase the efficiency of the procedure of electricity production is therefore imperative.
One method for more rational use in the production of electricity is the Cogeneration of Heat (or Refrigeration) and Power, where more than 4/5 of the fuels energy are converted in usable energy, resulting in both financial and environmental benefits.

Cogeneration is the consecutive (simultaneous) production and exploitation of two energy sources, electrical (or mechanical) and thermal, from a system utilising the same fuel. Combined heat and power production (CHP) is applied in industry and buildings where there is simultaneous demand of electricity and heat and, usually, when the annual hours of operation exceed 4000.

In the tertiary sector of Southern countries, the need for heating is limited to few winter months. There is, however, significant need for cooling (air conditioning) during the summer months. Heat by a cogeneration plant in this case is used to produce cooling, via absorption cycles. This "expanded" cogeneration process is known as trigeneration or combined heat, cooling and power production (CHCP)*.

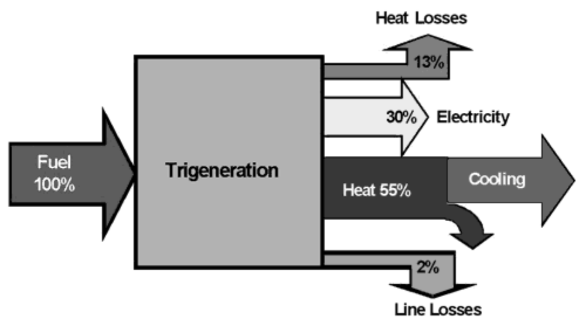

Figure 1. Combined heat, cooling and power production

The Table 1 and Table 2 summarise the range of main parameters concerning CHP systems and absorption chillers.

Table 1. The main parameters of CHP Systems

Engine	Gas Turbine	Steam Turbine	Combined cycle	ICE Otto/Diesel	Fuel cell
Power [MWe]	0.2-100	0.5-100	4-100	0.015-30	0.01-0.25
Heat/Power	1.25-2	2-10	0.5-1.7	0.4-1.7	1.1
Eff. Electric [%]	15-35	10-40	30-40	25-45	35-40
Eff. Thermal [%]	40-59	40-60	40-50	40-60	20-50
Eff. Total[%]	60-85	60-85	70-90	70-85	55-90
Minimum Load [%]	75	20	75	50	No limits
NO_x [kg/MWh]	0.2-2	0.9	0.2-2	1-14	<0.01
Usable temp. **[^oC]**	450-800	-	450-800	300-600	250-550
Use of heat	Heat, DHW, LP-HP steam, district heating	LP-HP steam, district heating	LP-HP steam, district heating	Heat, DHW, LP steam, district heating	DHW, LP-HP steam
Fuel	Gas, liquid	All	Gas,	Gas,	Gas

			liquid	petrol, diesel	

Table 2. The main parameters of absorption chillers

Indices	NH3 absorbtion	Li-Br absorbtion	
Effect	single	single	double
Cooling capacity [kW]	20-2500	300-5000	300-5000
Thermal COP	0.6-0.7	0.5-0.6	0.9-1.1
Temp. range [ºC]	120-132	120-132	150-170

*Triple effect chillers are not considered since the existing equipment workings under this effect are experimental machines. These machines have COPs (Coefficient of Performance) above 1.6 and operate in the temperature range 170 to 200 ºC.

Maintenance costs of absorption machines greatly vary according to the contract type.

In most cases outsourcing is used and the existing contract includes the maintenance of the whole air conditioning system. Often operation is also provided by outsourcing and the same firm provides under a single contract, the operation and maintenance of the whole system. In some cases the firm using the absorption chiller provides its own personnel to attend the operation of the AC system, and uses external services for period check-up (according to the maintenance programme established).

2. System performances

The main assumptions used in simulation of the CHP subsystem to obtain an indication of the amount and quality of heat generated by the CHP subsystem is summarised below.

- -Fuel cell operation at 70ºC and 700 mV cell voltage
- -Fuel utilisation is 80%
- -Oxidant utilisation is 50%
- -Thermodynamic equilibrium is assumed in all process stages
- -Adiabatic operation

The results of the modelling and simulation study are summarised in Table 1, Figure 2 and Figure 3. Figure 2 is a graphical representation of the amount of heat produced by the cogeneration system and the temperature level at which it is available (upper curve in the diagram). It appears that the major part of the heat available is low temperature heat from condensation of water vapour in the fuel cell/-afterburner exhaust stream at dew point (70ºC), and low temperature heat from the fuel cell cooling stream. To charge the SWEAT system, heat of 90-95ºC is required (curve below in the lower right hand corner). Clearly, only a limited amount of the available heat is suitable for use

in the SWEAT. The limited amount of useable heat, together with the relatively low COP of the SWEAT sorption heat pump leads to an overall cooling efficiency for the trigeneration system of about 7.7%.
The results shown in Figure 2 were used as input for a detailed SWEAT module to calculate the consequences for the SWEAT system performance and dimension.

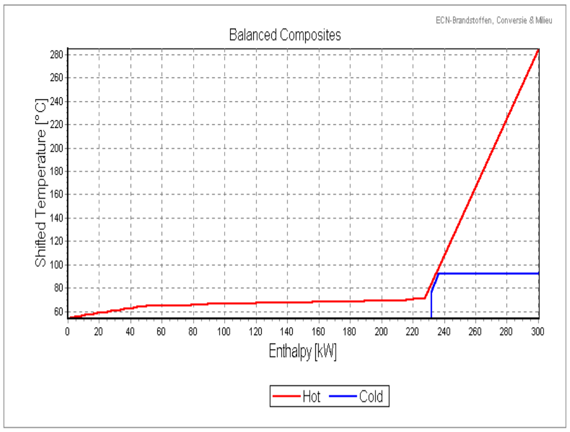

Figure. 2. Quantity and temperature level of the available heat of a 150 kW_e CPO-PEMFC cogeneration system, compared to the heat and temperature demand of the SWEAT system.

Table 3. Summary of calculated performance characteristics for the CPO-PEMFC-SWEAT trigeneration system concept

	Cogeneration Heat & Power	Trigeneration Cold, Heat & Power	Cogeneration Cold & Power
Natural gas	468	468	468
Net power	148	148	148
Net heat	301	232	-
Net cooling duty	-	36	36
Net electrical efficiency	31,6%	-	31,6%
Net thermal efficiency	64,4%	49,6%	-
Net cooling efficiency	-	7,7%	7,7%
Net total efficiency	96,0%	88,9%	39,3%

The efficiency results presented in Table 3 are presented in graphical form in Figure 9. The left side of the graph indicates the energy content of the fuel entering the system. In CHP mode heat and power are produced with efficiencies of 64% and 32%. About 23% of the heat produced, or about 15% of the total fuel energy input can be used for the production of cooling by the SWEAT, resulting in a system cooling efficiency of about 8%. Compared with CHP operation in trigeneration mode the overall efficiency decreases from 96% to about 89%. If the heat can not be used directly or stored for use later on, the efficiency further decreases to about 39%.

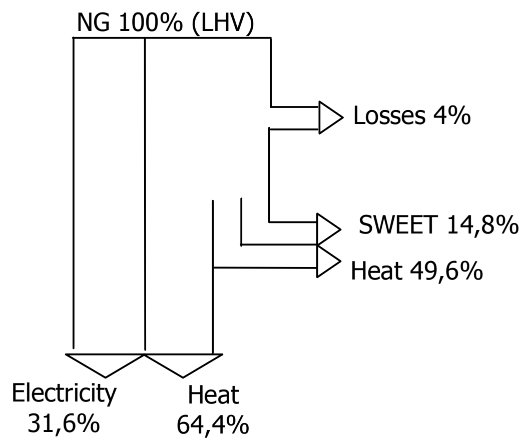

Figure 3. Breakdown of energy flow, "winter/CHP" versus "summer/CCHP"

4. Conclusions

The successful installation of CHP and CHCP leads to reduction of fuel consumption by approximately 25% compared with conventional electricity production.

The reduction of atmospheric pollution follows the same proportion. With the use of natural gas, rather than oil or coal, the emissions of SO2 and smoke are reduced to zero.

The benefits for the user are economic. Energy costs of trigeneration units are lower than those of the "conventional" units. In successful installations of CHP the price reduction is in the range of 20-30%.

The CHP station connected to the electric network, where it provides or absorbs electricity guarantees uninterrupted operation of the unit, in case of interruption of the station's operation or electricity supply from the network. On country level, it reduces the need of installation of large electric power stations and increases the stability of the electric network of the country. It also improves employment at local level.

Trigeneration units offer significant relief in electricity networks during the hot summer months. Cooling loads are transferred from electricity to fossil fuel networks, since the cooling process changes from the widespread compression cycles to the absorption ones. This further increases stability of electricity networks and improves system efficiency, since summer peaks are served by electric companies through inefficient stand-by units and overloaded electricity transmission lines.

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Addresses:

- Ş.l. Dr. Eng. Arina Negoiţescu, "Politehnica" University of Timisoara, Blv. Mihai Viteazu, No. 1, 300222, Timişoara, a.negoitescu@yahoo.com
- Drd. Eng. Adriana Tokar, "Politehnica" University of Timisoara, Blv. Mihai Viteazu, No. 1, 300222, Timişoara, adriana_tokar.@yahoo.com
- Ş.l. Dr. Eng. Daniel Ostoia, "Politehnica" University of Timisoara, Blv. Mihai Viteazu, No. 1, 300222, Timişoara, dostoia@yahoo.com